Urban Microgrids

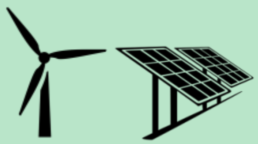
Overview, challenges and opportunities

PROJECT PARTNERS

Enedis, Fondation Tuck, Omexom, Groupe ADP, Total, Caisse des Dépôts

ENEA at a glance

ENEA is an independent consulting company, created in 2007, based in France (Paris) & Australia (Melbourne)



We are Energy & Environment specialists

From strategy consulting to projects and business support

We have a deep international experience and track-record

Europe, USA, Canada, Africa, Australia…

We have an ethical business model

Committed to energy access & positive impact (pro-bono business model)

Agenda

Microgrids overview and hotspots

Takeaways from 3 urban microgrids case studies

Main challenges and lessons learnt on urban microgrids

Conclusion and Q&A

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What is a microgrid?

It is a microcosm of the broader energy network including all the necessary components to **operate in isolation,** it has three key components: **Generation, Storage and Loads** all within **a bounded and controlled network**. **It may or may not be connected to the grid.**

SCOPE OF THE STUDY

Microgrids located in **developed countries** and satisfying an important local demand (~1+ MW of installed capacity)

Microgrid position in the "grid clustering" classification

	Components				Electric boundaries (1)	Islanding	Main grid interaction			Example
	Production	Storage	Load	Controller & EMS			Ancillary services	Local services to DSO	Energy market	
Embedded network	Not included	Not included	Included	Not included	Included	Not included	Not included	Not included	Not included	Shopping mall, Sydney
Virtual Power Plant	Included	Could be included	Could be included	Included	Could be included	Not included	Could be included	Could be included	Included	SmartGrid Vendée, AGL
Prosumers clustering	Included	Could be included	Included	Included	Not included	Not included	Not included	Not included	Included	EnR-Pool
Local prosumers clustering	Included	Could be included	Included	Included	Could be included	Not included	Not included	Not included	Included	FortZED, Colorado
Smart embedded network	Included	Included	Included	Included	Included	Not included	Included	Included	Included	GreenLys, Lyon
Microgrid	Included	Included	Included	Included	Included	Included	Included	Included	Included	Princeton University

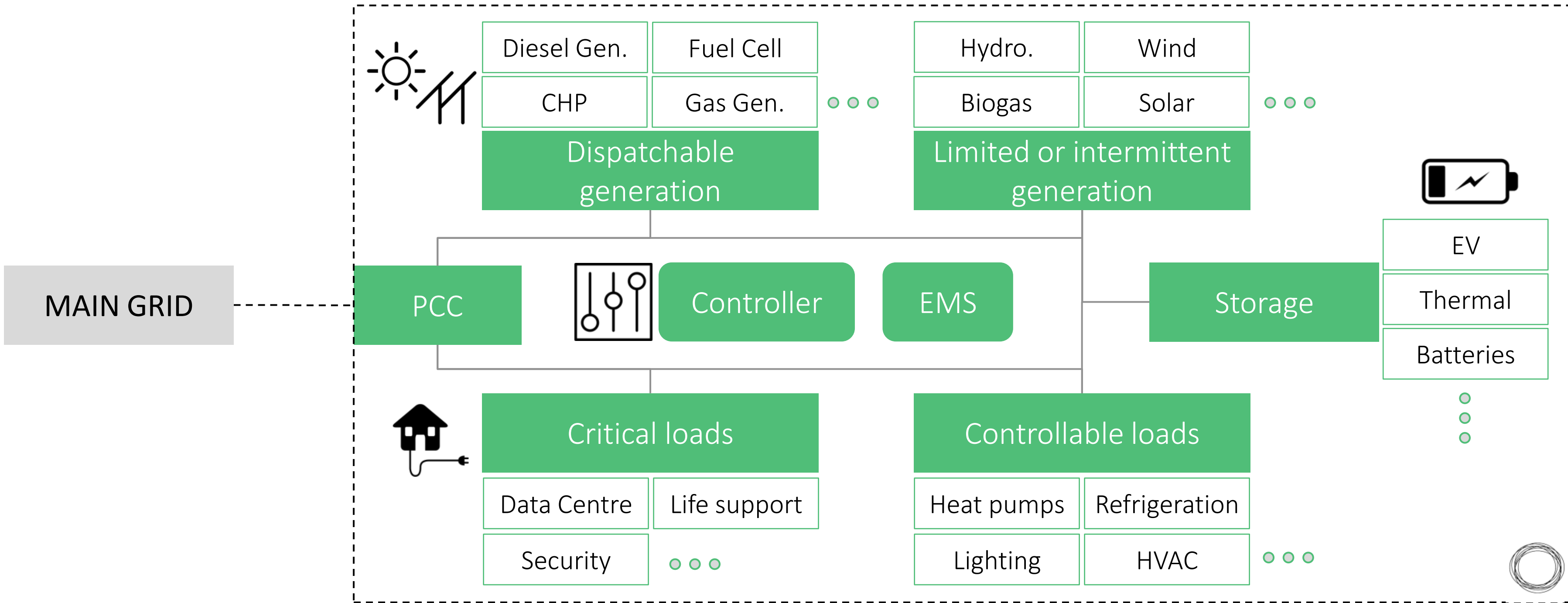
Included

Could be included

Not included

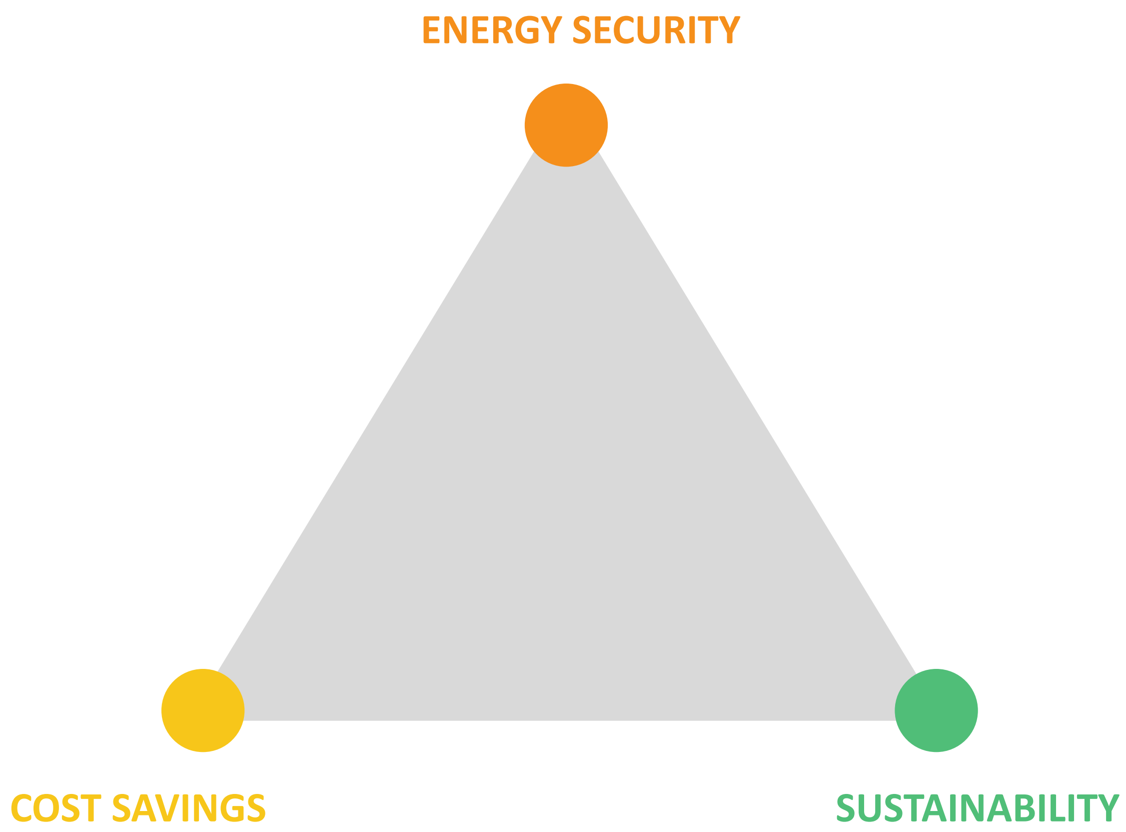
(1) With one or several connection points to the main grid

The Microgrid safely connects and disconnects from the main grid through the Point of Common Coupling (PCC)



General representation of a urban Microgrid

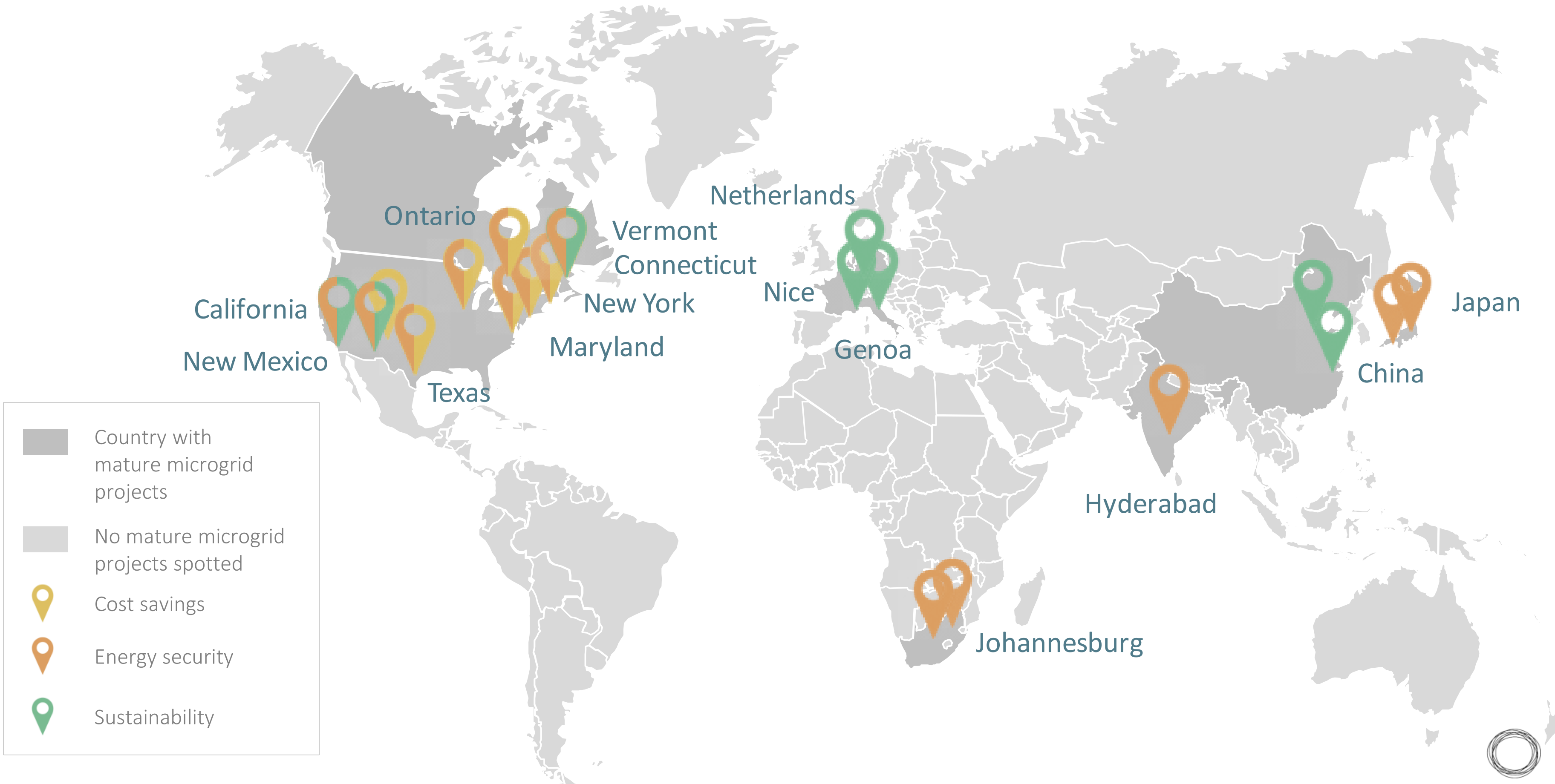
Microgrids structure can address 3 challenges: energy security, sustainability and costs reduction



The US are the most dynamic market for Microgrids

- **73 screened Microgrids commercial projects, 21 in focus represented on map below, 6 selected for detailed focus and interviews**

Major urban Microgrid hotspots worldwide (over 300 kW[(2)] projects)



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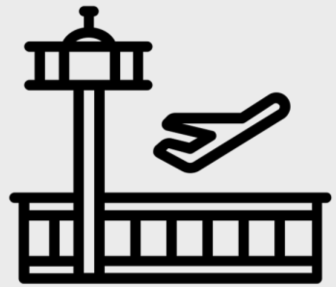
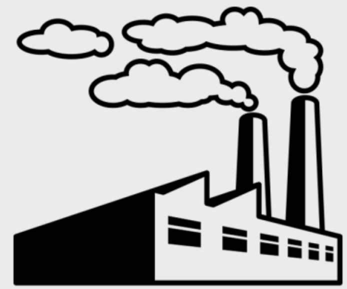
3 case studies were analyzed

ECO-DISTRICT



AIRPORT



INDUSTRIAL

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Methodology

Software used: HOMER ENERGY

HOMER optimises a microgrid design based on the desired components and a set of inputs and constraints:

- The software optimises the size of the components that have been integrated in the model beforehand.
- The model needs detailed yearly input such as load profiles, irradiance data and main grid energy and power prices.
- Optimisation results are framed by constraints on renewable penetration or the duration of islanding.

Main metrics:

- The Net Present Cost (NPC)

$$NPC = \sum_{i=0}^{n} \frac{(Costs - Income)\ in\ year\ i}{(1 + WACC)^i}$$

- The Levelized Cost Of Energy (LCOE)

$$LCOE = \frac{NPC}{\sum_{i=0}^{n} \frac{Energy\ consumed\ in\ year\ i}{(1 + WACC)^i}}$$

- Te renewable electricity penetration (%RE)

$$\%RE = 1 - \frac{Non - renewable\ energy\ production}{Energy\ consumed\ by\ microgrid}$$

A californian eco-district

ECO-DISTRICT

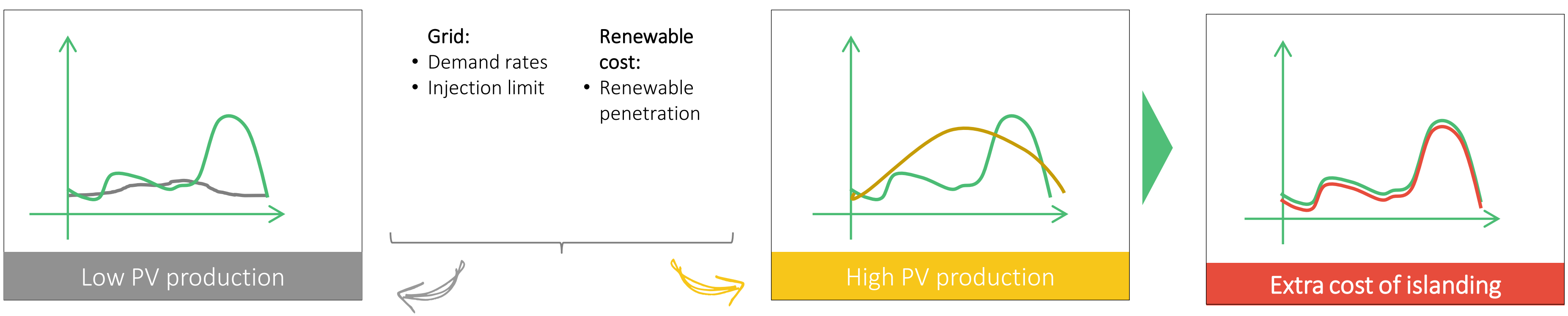
Case: Ecodistrict – Case study presentation

CONTEXT

- **Location:** San Diego, California
- **Microgrid owner:** The property developer
- **Main grid characteristics:** The Microgrid is connected to the secondary network
- **Loads:** annual ecodistrict consumption is ~4GWh
- **Generation mix:** solar panels and batteries
- **Modeling horizon:** 2020 - 2045

SIMULATION OBJECTIVES

1. Test a smart grid in an ecodistrict to evaluate the impact of drivers (cost savings vs sustainability) on the optimal generation mix
2. Determine the extra cost required to become a Microgrid – the same smart grid, that can now island from the main grid for 12 hours
3. Evaluate the influence of battery price, grid constraints and location on the key thresholds



1. BASE CASE | 2. SENSIBILITY | 3. ISLANDING

Case: Ecodistrict – Base case

Residential customer	Small business customer
287 \$/MWh(1)	229 \$/MWh(2)

Not included: franchise fees and taxes

Not included: franchise fees and taxes

Ecodistrict pooling
199 \$/MWh(3)

Not included: franchise fees and taxes
Included: 20 \$/MWh for private network

MAIN ASSUMPTIONS

- A 300-household Californian ecodistrict: all-electric, composed of residential and small businesses customers
- 2015 grid and market prices
- 2020 forecast technology prices

Case: Ecodistrict – Smart embedded networks

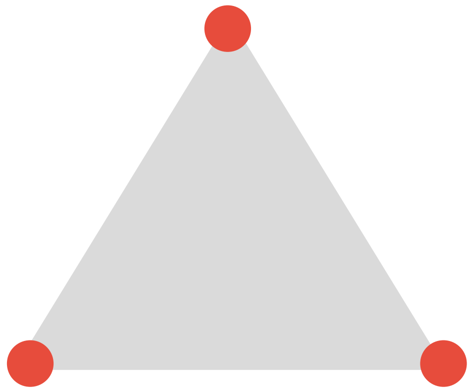
Microgrid

ENERGY SECURITY

800 kW demand
250 kW installed
100 kWh & 9.25 MWh installed

335 $/MWh
9% RE
12 hours islanding in peak summer day

Included: 51 $/MWh for private network, smart grid and islanding equipment



COST SAVINGS

800 kW demand
250 kW installed
100 kWh installed

196 $/kWh
9% RE
No islanding

Included: 27 $/MWh for private network and smart grid equipment

SUSTAINABILITY

650 kW demand
1 500 kW installed
500 kWh installed

199 $/MWh
49% RE
No islanding

Included: 27 $/MWh for private network and smart grid equipment

Case: Ecodistrict – Sensitivity analyses

BASE CASE

COST SAVINGS

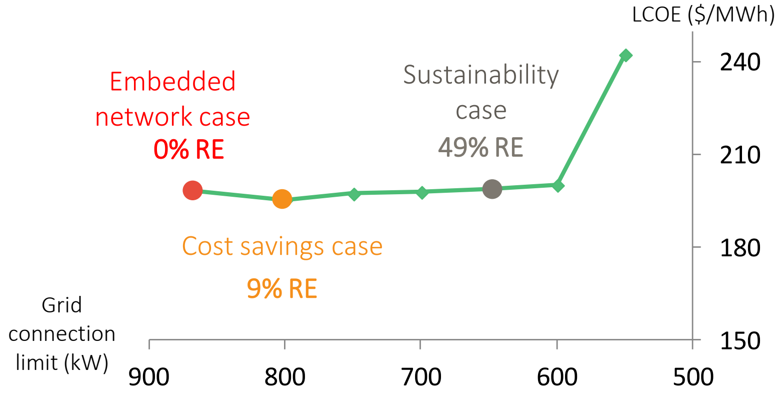
800 kW

250 kW

100 kWh

What is the optimal generation mix for limited grid supply?

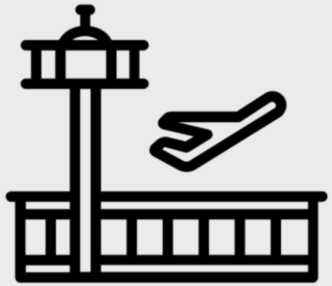
GRID SUPPLY AND INJECTION LIMIT DECREASE



Included in embedded network case: 20 $/MWh for private network
Included in smart grid cases: 27 $/MWh for private network and smart grid equipment

- Combination of deferrable load optimization, PV and battery is needed to make up for the limited grid
- Up to 30% reduction on grid interconnection (600 kW grid supply), LCOE is more profitable than grid-only scenario
- 30% reduction is a net threshold: then, on-site energy generation is more expensive and network reinforcement should be investigated

A French airport



AIRPORT

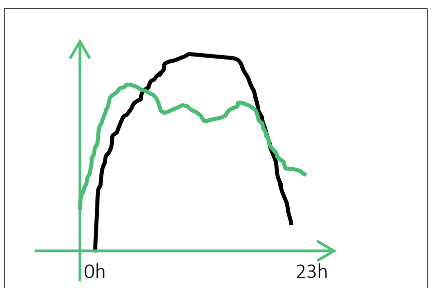
Case: Airport – Case study presentation

CONTEXT

- **Location:** France
- **Microgrid owner:** A small airport's authority
- **Main grid characteristics:** The Microgrid is connected to the French main grid
- **Loads:** annual airport consumption is ~4GWh
- **Generation mix:** solar panels
- **Modeling horizon:** 2025 - 2050

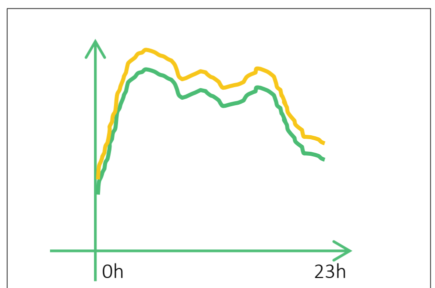
SIMULATION OBJECTIVES

1. Test a smart embedded network in a 100% electric airport that wants to produce as much renewable electricity as it could
2. Evaluate the impact of electrical vehicles and grid interconnexion capacity to optimize the system
3. Determine the extra cost required to become a Microgrid – the same smart embedded network, that can now island from the main grid



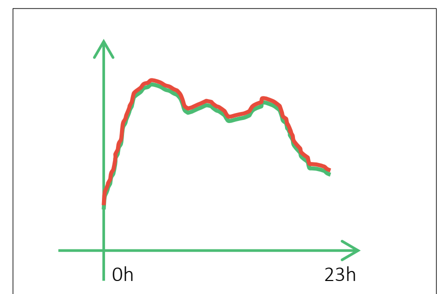
Low local production

1. BASE CASE



High local production

2. SENSIBILITY



Extra cost of islanding

3. ISLANDING

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Case: Airport – Smart embedded networks

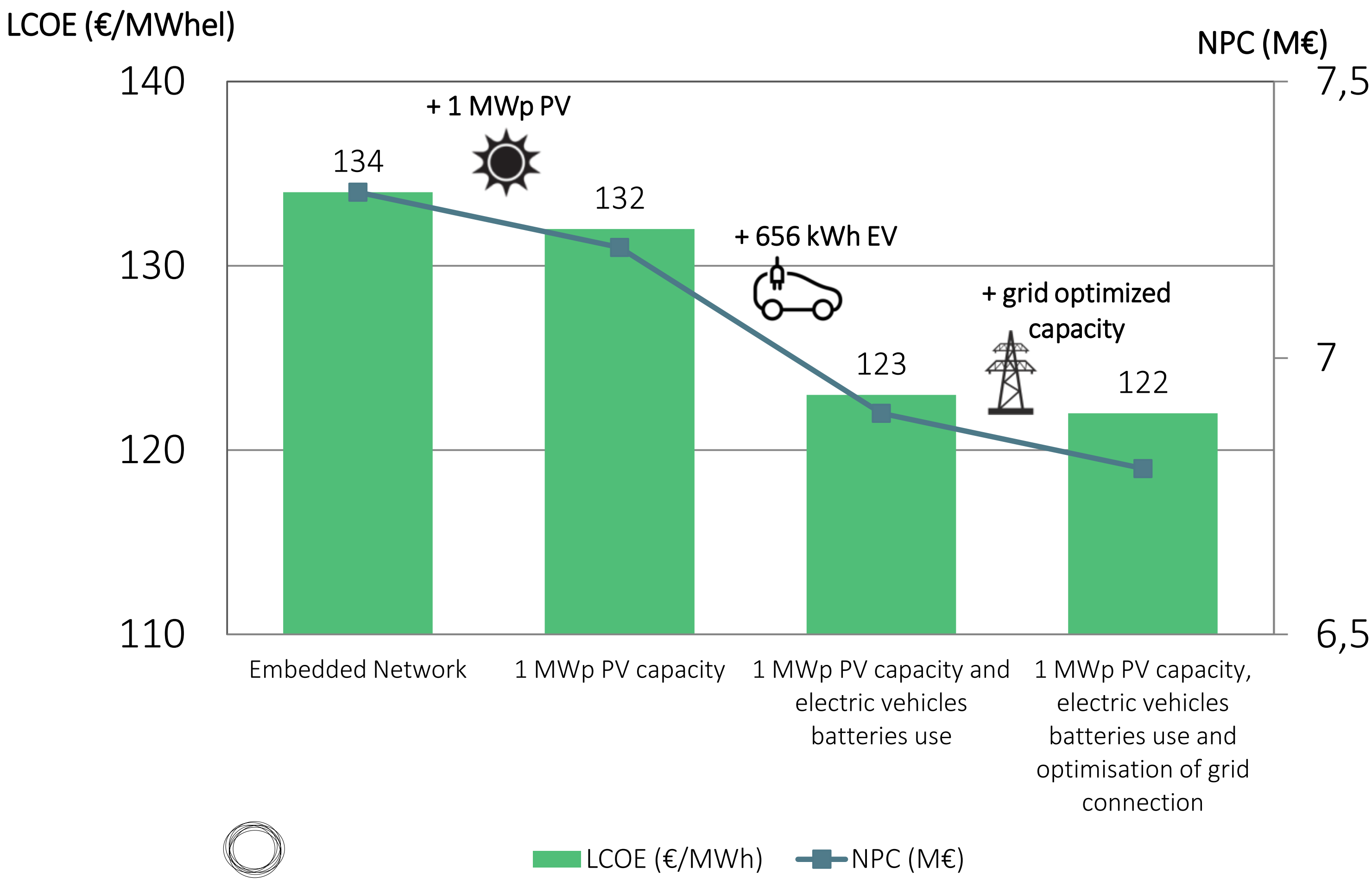
MAIN ASSUMPTIONS

- A 100% electric airport: consumption does not include the air traffic control
- The airport is equipped with electric charging points for electric vehicles
- Energy production: solar parking shelters (5.6 MWp) and batteries (16 electric vehicles – 656 kWh)
- Loads: lighting, HVAC, elevators, baggage sorting systems, sanitary, invertors, electric vehicles, etc.
- 2015 grid and market SPOT prices
- 2025 forecast technology prices
- Costs linked to electric vehicles batteries were assumed to be zero. Each day, an average of 16 vehicles are parked 24/24 which represents an available battery of 656 kWhel

Smart embedded networks

+ 4.2 GWh_{el} purchased	+ 2.4 GWh_{el} purchased - 3.2 GWh_{el} sold	+ 2.4 GWh_{el} purchased - 3.2 GWh_{el} sold
	+ 5.6 GWh_{el} produced *(5.6 MW_p installed)*	+ 5.6 GWh_{el} produced *(5.6 MW_p installed)*
		656 kWh_{el} EV battery
NPC M€ 7.33 *LCOE* €134,4/MWh	*NPC* M€ 10.17 *LCOE* €186,2/MWh	*NPC* M€ 10.16 *LCOE* €186,1/MWh

Case: Airport – Costs saving levers



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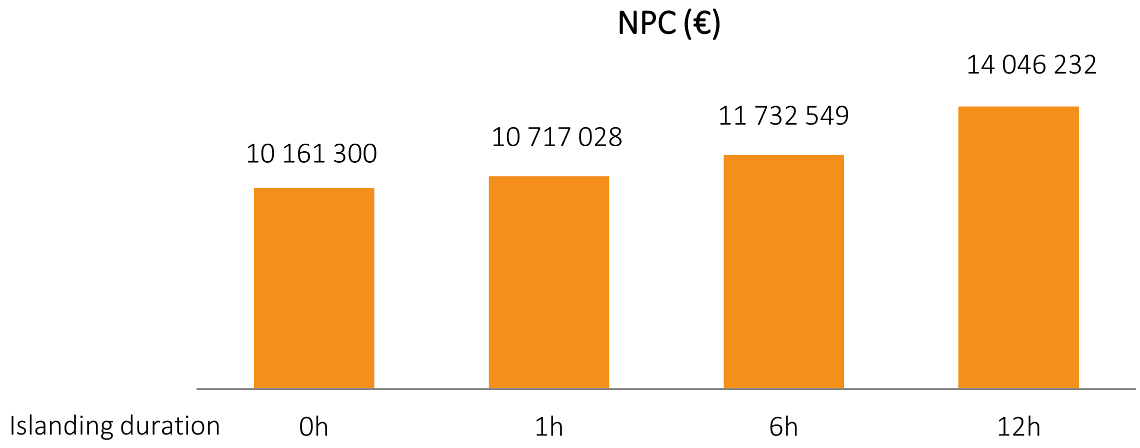
Case: Airport – Islanding

Microgrid

- PV installed capacity: 5 640 kW_p
- Use of clients electric vehicles battery: 0 kWh_{el}
- Maximum daily consumption (03/10/2015): ~15 000 kW_{el}



Battery size (kWh_{el})	0	1 150	3 500	7 500
Estimation of extra costs for islanding (€)	0	882 100	882 100	882 100

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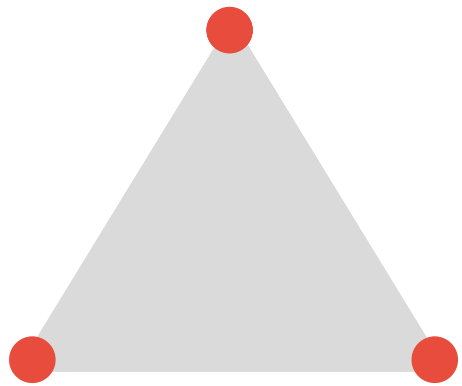
Case: Airport – Conclusions

ENERGY SECURITY

- Islanding duration depends on battery size: the longer it lasts, the higher the cost of energy. In France, grid outages are very rare and, when they occur, they last for under **1 hour**

LCOE = € 212/MWh (5.6 MWp PV)



COST SAVINGS

- Costs saving is possible through the installation of a **limited PV capacity** for auto consumption only, with **grid optimization interconnection capacity** and the use of electric vehicles batteries for **vehicle to grid**

LCOE = € 124/MWh (1 MWp PV)

SUSTAINABILITY

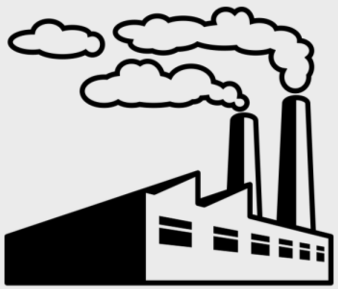
- The maximum renewable achievable with land constraint is 42.4% (5,6 MWp PV)

LCOE = € 186/MWh(5.6 MWp PV)

- Without land constraint, and for an installed capacity of 10 MW (47.5% of RE)

LCOE = € 223/MWh (10 MWp PV)

A French industrial park



INDUSTRIAL

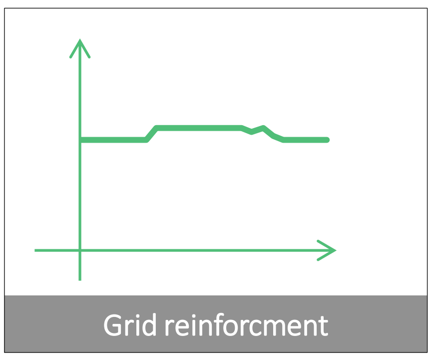
Case: Industrial – Case study presentation

CONTEXT

- **Location:** France, Bretagne
- **Microgrid:** Industrial zone (agribusiness) with growing activity
- **Main grid characteristics:** HTB1 connection
- **Loads:** Electric: 70 Gwh_e-Heat: 106 GWh_{th}-Cold: 53 GWh_{th}
- **Peak for electric load:** 10,9 MW_e
- **Generation mix:** trigeneration unit and solar panel
- **Modeling horizon:** 2020

SIMULATION OBJECTIVES

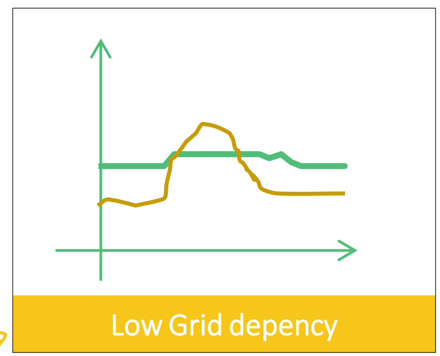
1. Test a smart grid for a growing industry with HVAC loads, located in a congested region, with a distribution network that cannot provide 100% of the needed electricity for its loads
2. Evaluate the impact of electricity price and load suitability for trigeneration and flexibility
3. Determine the extra cost required to become a Microgrid – the same smart grid, that can now island from the main grid for 24 hours



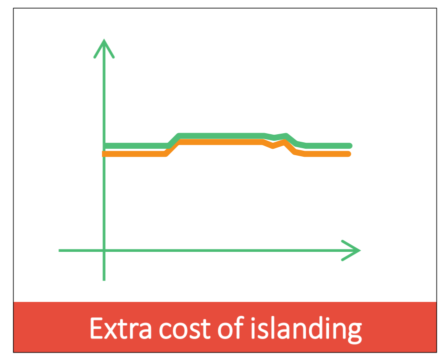
1. BASE CASE

Grid electricity
- SPOT price
- Grid subscription tariff

Load profile
- Ratio between electricity, heating and cooling loads
- Shortage time allowed for non-critical load



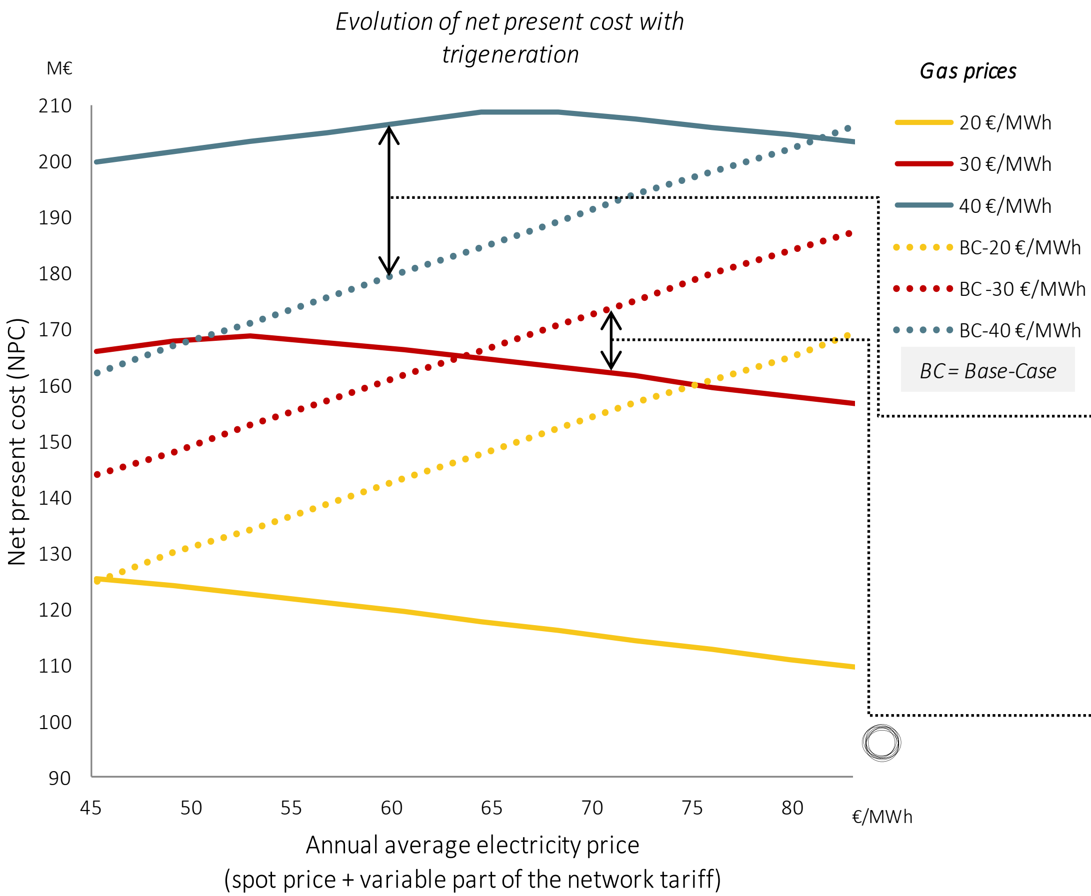
2. SENSIBILITY



3. ISLANDING

Case: Industrial – Sensitivity analysis

Cost of grid reinforcement has a low impact on the choice of trigeneration, which depends mostly on electricity and gas prices[1]



ANALYSIS

- Once trigeneration unit reaches 12 MW_{el}, incomes from energy sales to the main grid increase with electricity prices, leading to a decreasing NPC. Before that, system optimization leads to a 4 MW_{el} with 2 MW_p of solar panels because of gas prices.
- Installing trigeneration unit protects the owner of the grid of electricity spot prices variation

EXAMPLE 1

- For a gas price of 40€/MWh_{PCS}, trigeneration unit is not valuable regarding electricity prices. This is true as long as the grid reinforcement costs are not higher than the difference between the 2 curves [2]

EXAMPLE 2

- For a price of 30 €/MWh_{PCS}, installing a trigeneration onsite is valuable once electricity price is over 63 €/MWh_e

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Case: Industrial – Analysis

COST AND BENEFITS OF THE GRID CONNECTION

- Public network tariff with the same power subscription (12 MW_{el}) but a consumption divided by 10:
  - Fixed part: 165 000 €/year
  - Variable part: 50 000 €/year
- The extra cost for islanding is low (250 000 €) because the grid has already a flexible generator able to supply all the internal demand
- The benefits of arbitrage with the grid depends on gas and electricity prices:

Average electricity price (spot + variable part of TURPE)	Gas price	Generator load ratio (min: 70%)	Electricity sold – average price	Electricity purchased – average price	Net benefits/year
45 €/MWh_{el} (2016)	30 €/MWh_{PCS}	84%	6,4 GWh_{el} – 48 €/MWh_{el}	3,6 GWH_{el} – 34 €/Mwh_{el}	0,2 M€
65 €/MWh_{el} (+50%)	30 €/MWh_{PCS}	91,5%	25,6 GWh_{el} – 42 €/MWh_{el}	0,3 GWh_{e} – 25 €/MWh_{el}	1,1 M€

- Profits generated by electricity selling to the grid and by demand response mechanism (non considered in this model) compensate the cost of grid connection

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Best conditions for a cost-effective urban microgrid

Embedded smart networks (no islanding) are more adapted than microgrids (islanding) in presence of a high share of intermittent energy production in urban areas

- Local production of greener and more affordable energy can also be achieved without introducing the islanding capability of microgrids
- Grid tariff structure, origin of the yearly peak demand (heating or A/C) and availability of renewable resources are the three significant sizing factors in the economic optimisation of such networks
- Vehicle-to-Grid technologies can optimize the power demand profile of the microgrid and decrease costs

Microgrids can be economically profitable in presence of a high share of dispatchable energy production and thermal energy demand

- Microgrids capabilities (including islanding) have been found economically relevant in this study only for applications with a strong heat demand (or heat and cold demand), such as demonstrated in industrial zones

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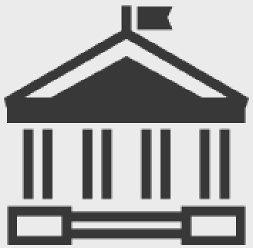
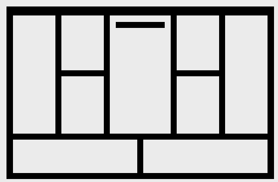


REGULATION



BUSINESS MODELS

TECHNOLOGY AND COSTS

REGULATION

Regulatory challenges (1/2)

	Challenges	Examples of regulations / trends
Microgrids regulatory status and franchise right	Regulation used to define the status of the distribution operator and/or the independent producer can be constraining E.g. reporting mechanisms, right to use public domain, etc.	– **Europe**: CDN regime implies possibilities of exemption on market based procedures to cover energy losses and on prior tariff approval from regulatory authority (directive 2009/72/CE,Art.26) – **US**: • Qualifying facilities status can be applied for some customer-owned Microgrids • States can have liberal DSO franchise framework (Ex: Connecticut) • Partnering with local owner of the concession and/or municipalities can simplify Microgrids implementation • Municipality have sometimes the right to own and operate electric utilities
Ownership unbundling	Ownership unbundling can threaten Microgrids development E.g. in most existing projects, Microgrid operator and producers are merged into the same corporation	– **Europe:** the directive 2009/72/CE (Art.28 §4) offers possibilities of unbundling exemption, which can be transposed in public law (Hungary, Finland, County of Flanders[1])
Protection of consumers rights	In specific cases, protection of final users rights is more complex with Microgrids E.g. free choice of supplier, transparency, right of appeal, etc.	– **Europe:** • Internal metering ensures the customer right to freely choose its supplier (**France and Germany**: closed distribution network, indirect grid connection, self-consumption) • Final users can ask the regulatory agency to approve the CDN tariffs

[1] *"Status Review on the Implementation of Distribution System Operators' Unbundling Provisions of the 3rdEnergy Package", Council of European Energy Regulators (CEER), April 2016 & "Closed distribution Networks", Energy Regulator Regional Associations (ERRA), March 2013*

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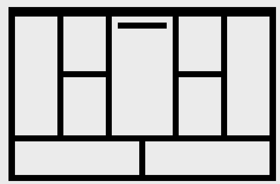
Regulatory challenges (2/2)

	Challenges	Examples of regulations / trends
Network tariff	The structure of public network tariff is sometimes not adapted to the consumption of Microgrid users E.g. fixed costs applied to a smaller rate base	– **Europe:** in most cases, the standardized public tariff is paid according to the net consumption of Microgrid users (Germany, France for CDN, etc.) – **France**: a specific public network tariff for collective self consumption under 100 kW of generating power will be defined by the regulatory agency
Electricity taxation	Microgrid taxes on electricity do not always cover taxes of the main grid that are supporting national solidarity and energetic transition E.g. tariff equalization, support for renewable energies, etc.	– **Germany:** specific tax exemptions on EEG contribution are applied to individual self consumption in Germany, but not to collective one with direct selling to final users with or without using public network (direct delivery) – **Spain:** a dedicated tax on self consumption was created in 2015 (the “sun tax”)
Islanding regulation	Microgrid connection and disconnection to the main grid are not clearly defined in the regulation E.g., inability to reconnect the Microgrid because of technical and/or economic reasons	– No example found: there is a need for a clearly defined procedure for post islanding reconnection

Changes need to be made in the grid regulatory framework in order to allow operational implementation of microgrids

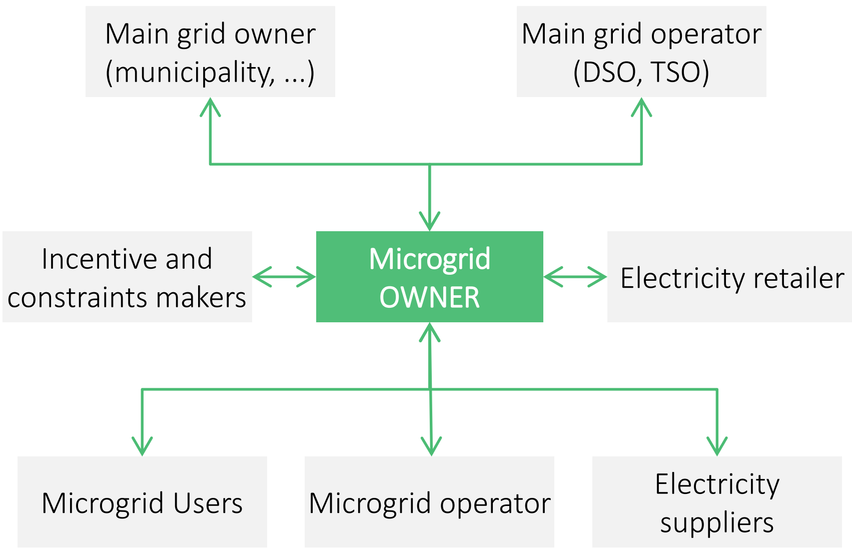
- Clearly defined **disconnection and reconnection procedures**, as well as ancillary services to the main grid.
- Current **network tariffs structure** should evolve to reflect more adequatly the service provided.
- **Taxes on electricity** consumed within the microgrid should support national objectives such as energy transition and national solidarity.
- Microgrid operators should work under an adequate regulatory regime, especially regarding **unbundling requirements** for vertically integrated structures.
- **Status of microgrid stakeholders** (operators, prosumers, etc.) should be adapted to prevent an excessive administrative and financial burden.
- **Final users rights** within the microgrid, especially the right to **freely choose suppliers**, may be more efficiently ensured by a dedicated regulatory framework.



BUSINESS MODELS

Microgrids ecosystem and value streams

MANY STAKEHOLDERS ARE INVOLVED IN MICROGRIDS ECOSYSTEM



AN ECOSYSTEM WHICH OFFERS NUMEROUS VALUE STREAMS

Services to the system operator (national)

- Frequency and voltage regulation
- Spin / non-spin reserves
- Black start
- Demand-response

Public subsidies

- Feed-in-tariffs, green certificates, etc.
- Self consumption

Energy arbitrage

- Energy injected into and taken from the main grid

Local services to the DSO

- investment deferrals

Quality of supply

- Energy security
- Higher rates of DERs
- Power sale contract

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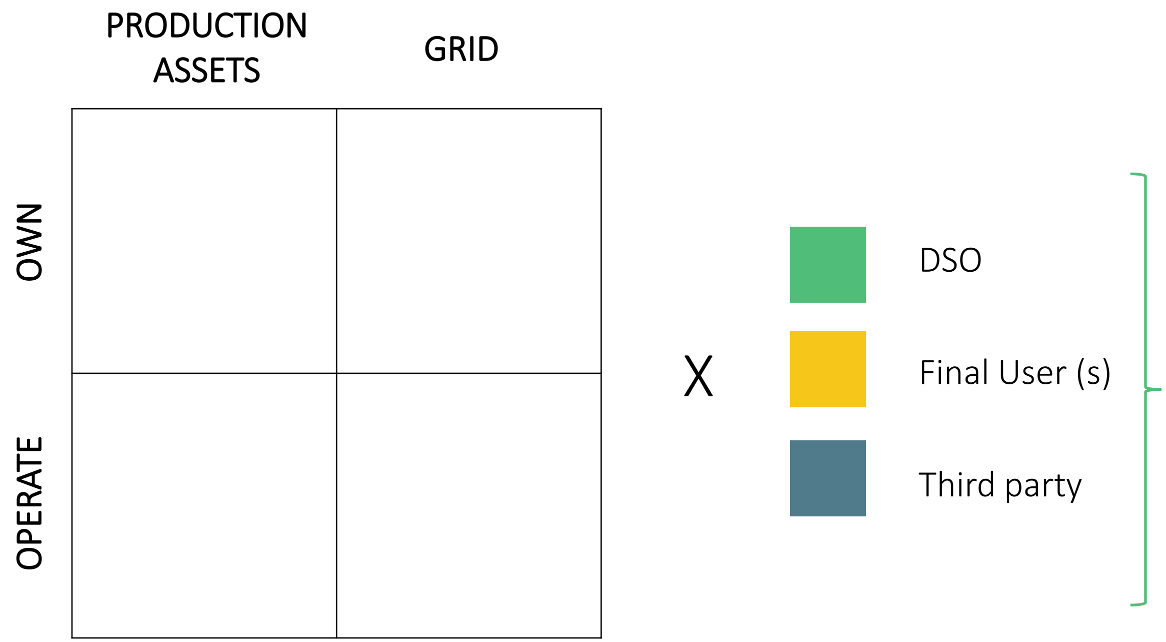
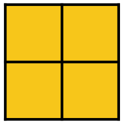
The methodology used to identify business models



81 possibilities, of which only 9 are relevant

(economic constraints)

Examples:

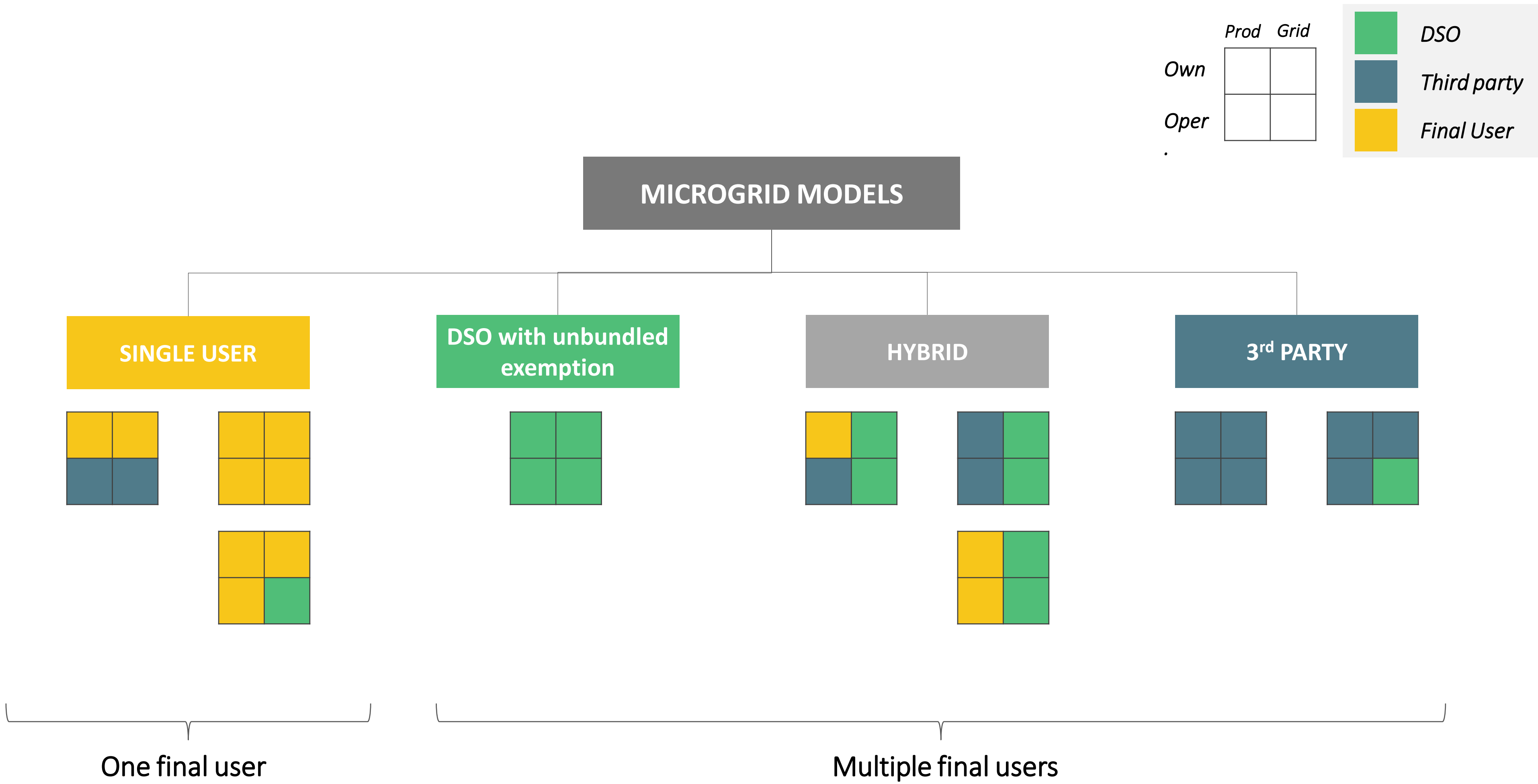


A single user with multiple facilities owned by that end user (hospital, industrial, etc.)

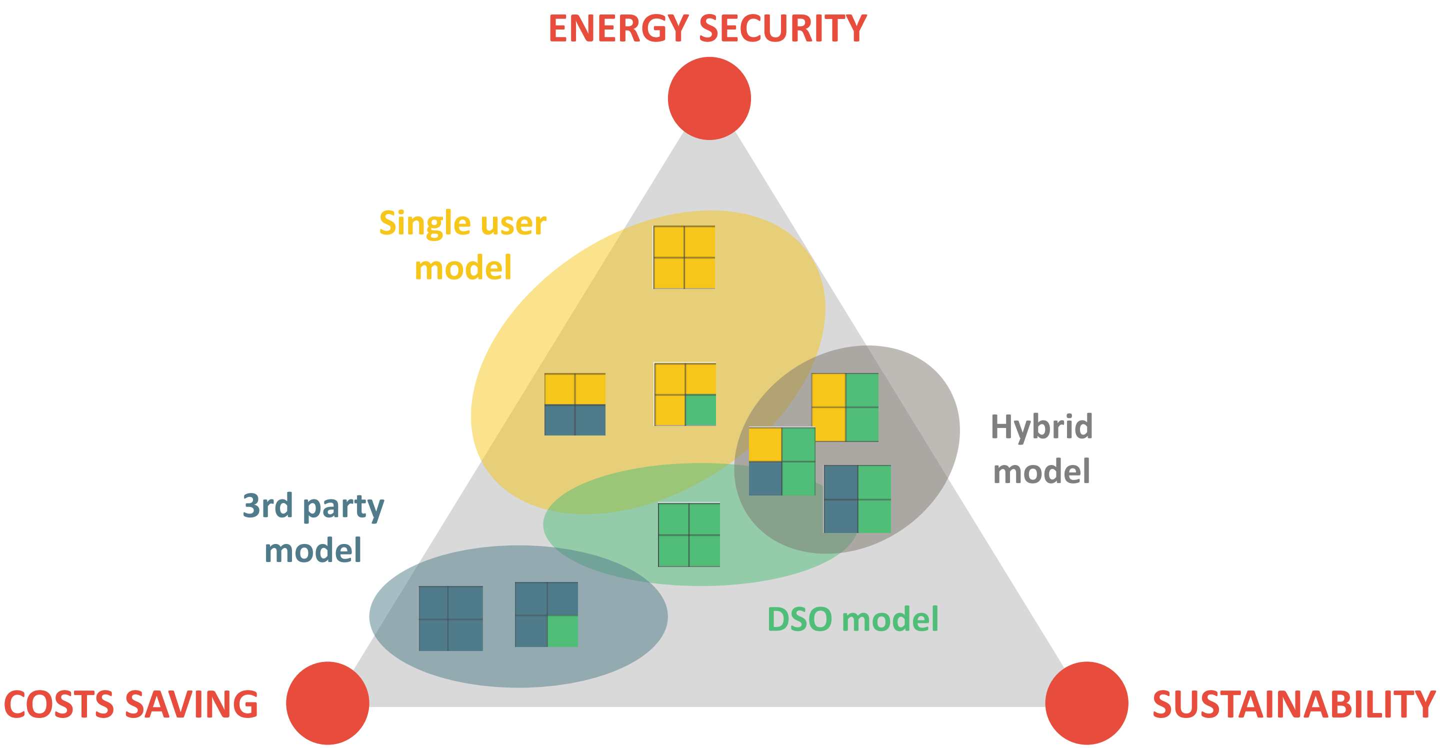
No economic reason for a DSO to only own generations assets

A final user has no interest to only operate the generation assets owned by a third party

This methodology enabled to identify 9 relevant business models for Micrograms

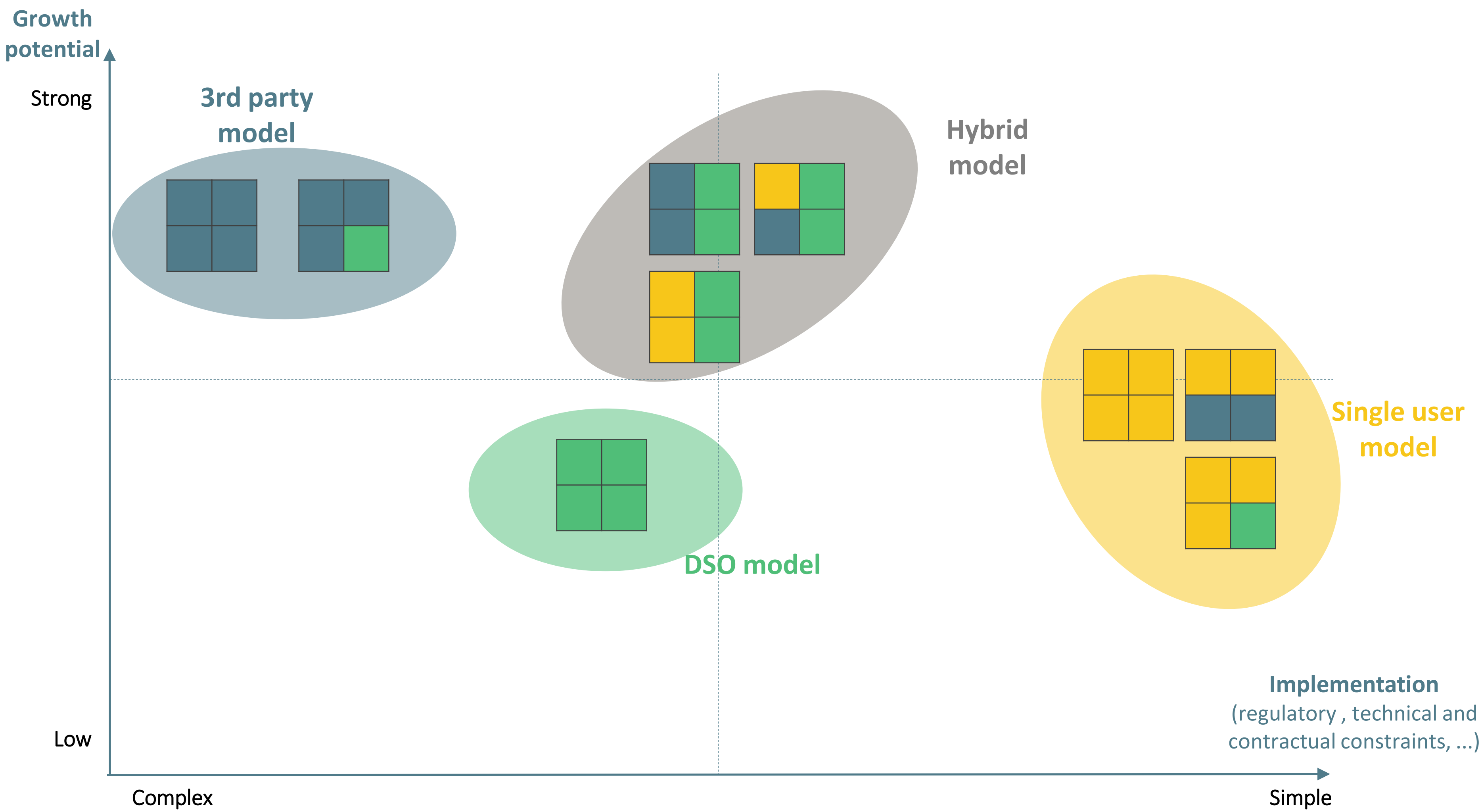


The 4 business model may respond to different drivers …



Source: ENEA consulting Analysis

… and present different growth opportunities



Sources: ENEA consulting Analysis

TECHNOLOGY AND COSTS

Main technical challenges of microgrids can be overcome with existing technologies, even if the solution comes at an extra cost (1/2)

Selected challenges

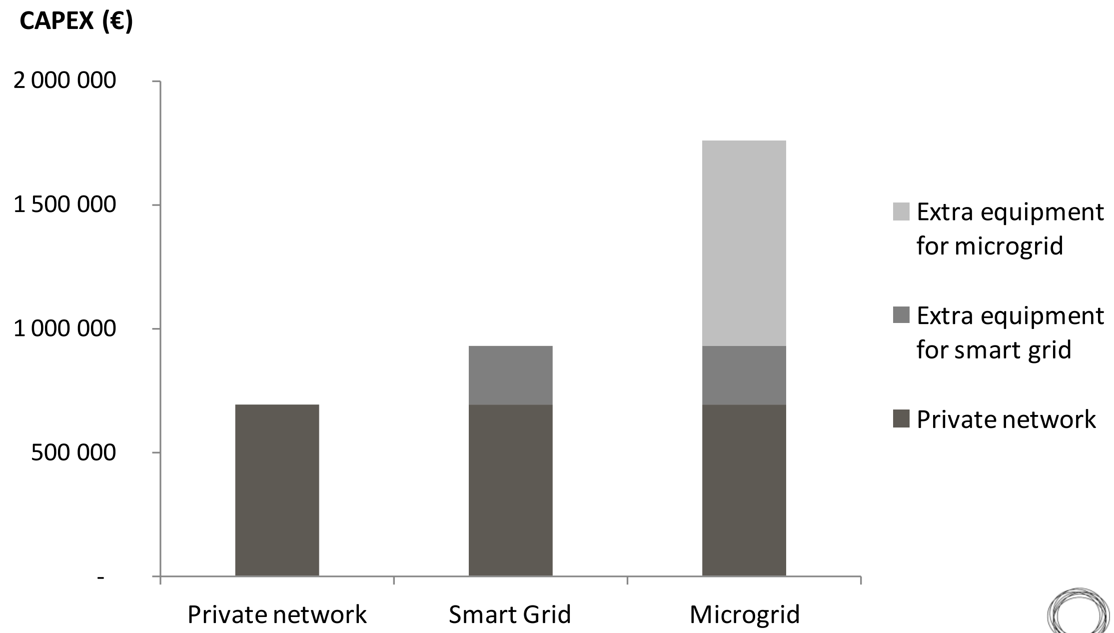
Challenge		Selected challenge
Comprehensive control system: how to find an affordable system and able to manage generation, load, frequency and voltage	▶	Controls
Assets protection: islanded mode requires special protection system	▶	Protection
Compatibility with main grid protection infrastructure **Power quality:** harmonic distortion, frequency and voltage regulation **Out-of-phase reclosing:** microgrid must synchronize with the main grid after islanding	▶	Re-synchronization
Compatibility: generation, distribution and loads have different specifications (voltage, AC or DC,…)	▶	Direct Current

Fast islanding detection **Black-start** **Flexibility in design:** compatibility of microgrid assets, especially if microgrid evolution in time - new assets or demands…	▶	Technical challenges important to the development of an ideal microgrid, but not crucial for the core functions
Operators safety, when microgrid stays energized during main grid outages **Security against external threats:** terrorist, cyber attacks	▶	Technical challenges that should be overcome by non-technical solutions: procedures, preventive measures, trainings…

Main technical challenges of microgrids can be overcome with existing technologies, even if the solution comes at an extra cost (2/2)

Controllers' price can be reduced by limiting case-by-case customization	Comprehensive control system need to be able to: • make the switch between connected and islanded mode • manage generation, load, frequency and voltage during islanding
Protection of electrical assets might be an issue in specific topologies, it should then be ensured by advanced equipment	Microgrids with distributed generation usually have lower fault currents. A simple short-circuit can lead to the failure of the microgrid if not detected early enough.
Re-synchronisation of microgrids to main grid can be completed with very little impact on main grid	Out-of-phase reclosing is the phase when Microgrid might have a negative impact on main grid's performance: it can produce unexpected transients released on local distribution network.
Direct Current microgrids are an opportunity for cost savings but are not widely known by stakeholders	With DC network, a Microgrid can connect PV and batteries (DC sources) directly to DC loads. There are less costs from conversion losses, islanding doesn't need a mechanical switch, control system is cheaper, power quality is higher. But there is a lack of standards, safety issues, and higher upfront cost if there are two circuits (AC and DC).

Whatever the complexity and the energy security levels are, Microgrid requires extra cost to enable the islanding feature

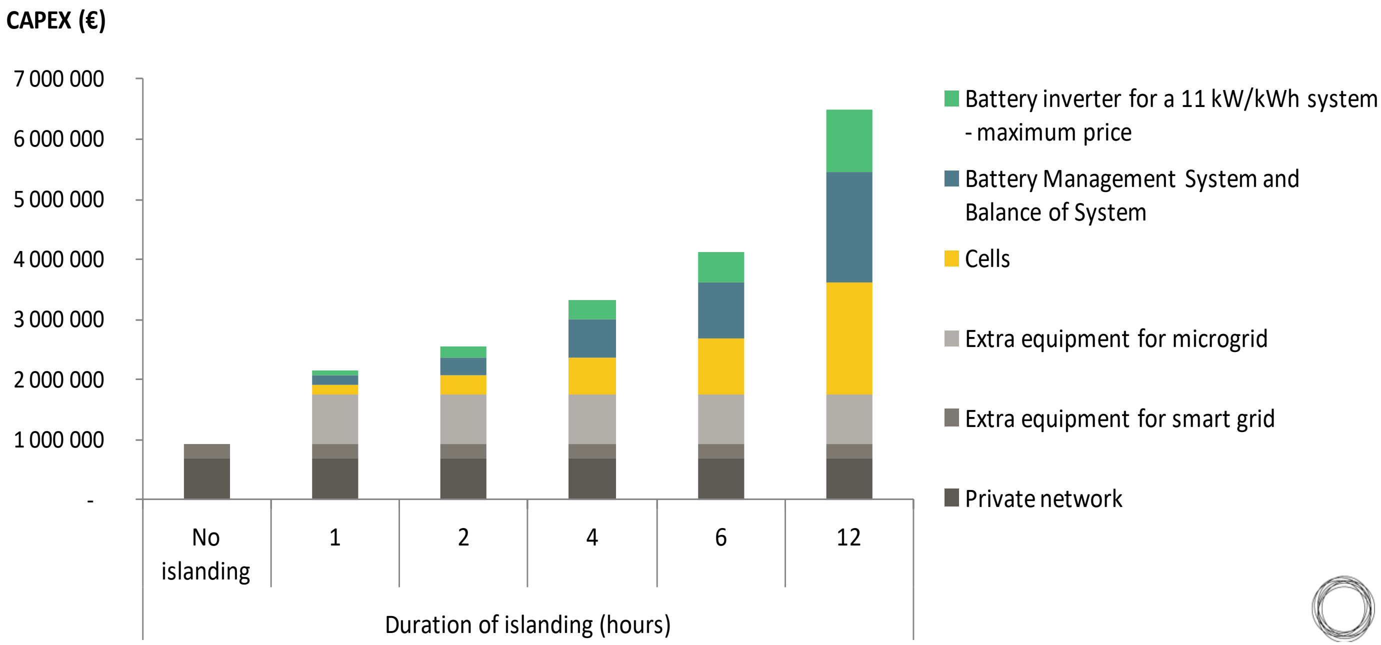


Private network CAPEX is highly dependent on the spatial extension of the project

Smart grid with distributed generation entail additional costs, mainly for the design of a centralized controller

Microgrid overcost is due to the islanding feature that requires additional hardware and software

Extra hardware and software represent the main cost for short islanding times, but is offset by battery cost for long islanding times



The size of the battery is directly linked to the duration of islanding

The battery is not cycled and kept as a back-up in case of outage

Switching from no islanding to a 1-hour islanding more than doubles the initial CAPEX

- 57% of the additional CAPEX is due to hardware and software elements that enables the islanding feature
- 43% is due to battery CAPEX

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Agenda

Microgrids overview and hotspots

Takeaways from 3 urban microgrids case studies

Main challenges and lessons learnt on urban microgrids

Conclusion and Q&A

Conclusions

- Technical hurdles implied by islanding can be overcome with existing solutions, but might bring about substantial cost

- Embedded smart networks (no islanding) are more adapted than microgrids (islanding) in presence of a high share of intermittent energy production in urban areas

- Microgrids can be economically profitable in presence of a high share of dispatchable energy production and thermal energy demand

- Both microgrids and embedded smart networks face major regulatory obstacles today, limiting the emergence of new promising business models

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